Inertial Sensors Enable Automotive Safety

Mike Layton, Customer Adaptation Center Manager, Systron Donner Automotive

Miniature solid-state inertial sensors are now in widespread use in passenger cars and SUVs with electronic stability control (ESC) being one of the primary high-volume applications. Tens of millions of gyros and accelerometers have been installed in vehicles since ESC first appeared in 1995. The primary ESC inertial sensors are a yaw sensor that measures vehicle turn rate and an accelerometer that measures side-to-side acceleration. The success of these sensors can beattributed to the use of extremely stable micromachined structures made from crystalline quartz and silicon with no moving parts and corresponding fatigue failure. Performance of today's automotive inertial sensors is comparable to aerospace sensors used 20 years ago, but at a significantly lower cost. Automotive volumes and profit potential have driven inertial sensor suppliers such as Systron Donner Automotive, VTI, Bosch, and others to do what many inertial sensor experts thought couldn't be done in terms of performance, volume, quality and cost. The recently-announced National Highway Traffic Safety Administration (NHTSA) legislation mandating ESC on all U.S. passenger vehicles, SUVs, and light trucks by model year 2012 has further spurred market interest in this technology. Today there is a great deal of activity by OEMs, Tier 1 brake system suppliers, and the inertial sensor community to determine the best approach to packaging and locating the inertial sensors in future vehicles.

The tuning fork sensing element inside the Systron Donner Automotive MicroGyro is micromachined of pure piezoelectric crystalline quartz.

First, a brief introduction to the inertial sensors. The yaw-rate sensor used in ESC

systems is a single-axis gyroscope also known as an angular-rate sensor or simply a rate sensor. Today's designs are all of a class of gyros known as vibrating Coriolis-effect sensors, and they operate by establishing a vibrating linear momentum in space which resists motion when rotating, resulting in a secondary vibration that is detected and converted to angular rate. This type of gyro is wellknown and has been used in aerospace applications since the 1950s. What has changed is the use of micromachined quartz and silicon MEMS structures, making the gyros well-suited for highvolume automotive manufacturing.
A unique trait of the gyros is that they vibrate and are mechanically "live." Vibration frequencies range from 10 kHz to 25 kHz and are a function of the sensing element size and design. Sensor package design requires great care by the sensor supplier in order to eliminate parasitic effects, also making it much more difficult for gyro suppliers to integrate multiple sensors (yaw-pitch-roll, for example) in a single package. This is a fundamental difference between gyro and accelerometer sensors. Many of the problems encountered historically by gyro users occur at linear and torsional vibration frequencies well above the sensor's operating bandwidth, and clear specifications from OEMs and Tier 1 suppliers are just now beginning to reflect these issues. A good example is the "gravel test" performed by OEMs in which stones impact the underbody of a car to which the gyro is mounted.

The low-g lateral accelerometer is the other primary ESC inertial sensor whose function is to measure side-to-side vehicle acceleration. These sensors employ micromachined silicon massspring structures which flex under g-loading. The tiny static displacements of the proof mass are detected via changes in capacitance between the sensing element and frame, and are converted into linear signal information via a custom ASIC within the package. As with the gyro, automotive market pressures have driven suppliers to develop g-sensors with outstanding performance, size, cost and quality. In addition, the accelerometers are now widely available in two-axis and threeaxis packages. VTI Technologies and Analog Devices exemplify successful suppliers of low-g automotive accelerometers and offer products in a variety of configurations.

In order to reduce overall ESC system costs, there are efforts underway by Tier 1 suppliers to integrate the inertial sensors directly onto the brake ECU circuit board under the hood. This eliminates the need for a separate sensor package in the passenger compartment, with corresponding cabling and installation cost. It also eliminates the need for some of the sensor package content, such as the microcontroller, CAN transceiver, power management and EMC protection. The problem is that, from an environmental standpoint, the underhood location is the worst place one could conceive of to place the inertial sensors. Operating temperatures exceed +125°C and because the ECU board is mounted directly to the brake modulator body, there is a large amount of high-frequency linear and torsional vibration. These issues notwithstanding, sensor suppliers have been able to provide parts capable of operating in this environment while maintaining excellent inertial performance. Systron Donner Automotive achieved this by designing the ASIC and packaging from the outset with the underhood temperature and vibration environment in mind.

Another option being considered by OEMs is the integration of the ESC inertial sensors into the restraint-control module (RCM) located in the passenger compartment. This approach has all the advantages of the previously-discussed, but without the major disadvantage of the underhood environment. Success with this approach depends less on performance under severe environmental conditions than it does on the RCM and ESC engineers working collectively on module design and requirements. The RCM engineers are already familiar with inertial sensors, as they use them to measure when conditions justify firing the airbags.

TIMUs could be the next evolution in automotive safety electronics. This one unit has the capability to consolidate every angular-rate sensor and accelerometer in a vehicle to measure multiple axes of angular-rate and acceleration change.

A third option is to continue to locate the ESC inertial sensors in a standalone module in the passenger compartment. This approach is in production today by most OEMs. The inertial packages offered by different suppliers are more alike than different, each containing a yaw-rate sensor, accelerometer, microcontroller, CAN transceiver, and power/EMC components all on a single PC board in plastic housing with integral connector. The inertial package is typically located under one of the front seats or in the center console. Communication with the ECU is via a two-wire digital CAN interface. Although a time-proven approach, no cost advantages are gained from sharing functions with another module. Cost reduction possibilities are limited to reducing component and manufacturing costs.

A final option worthy of consideration is a standalone Inertial Measurement Unit or IMU that contains pitch, roll and yaw gyros, and X-, Y- and Z-axis accelerometers. Such a device would be integrated on a single PC board similar to today's yaw-lat ESC inertial sensor modules. By including the additional sensor channels several advantages are gained. One is the ability to eliminate misalignment errors between the inertial sensors and the package mounting references. This is only possible when all three sensing axes are present and would be done by the IMU supplier during final calibration of the device. A second advantage is the ability to mount the IMU in any orientation, and via platform-specific algorithms, rotate the inertial data to align with the vehicle axes. The third and biggest advantage is that an IMU measures all possible vehicle motions, and high-quality inertial data could be provided via CAN interface for all vehicle functions, including ESC, lane-keeping, GPS aiding, ride control, and any additional future applications. Today several accelerometer suppliers offer high performance three-axis devices in a single package, and several rate-sensor suppliers are offering in-plane and perpendicular-axis sensing packages, providing all the necessary building blocks for a single-board IMU. One can conceive of additional functions built into the IMU such as continuous recording of inertial data for crash reconstruction or fleetmonitoring applications. Parents of teenage drivers might also want to plug into the family car on occasion and see what has been going on. As future vehicles include more and more systems requiring accurate inertial data, the centralized IMU approach will become more attractive to the OEMs from a total cost standpoint.

--Mike Layton, Customer Adaptation Center Manager, Systron Donner Automotive